Relative Merits of Distributed vs. Central Photovoltaic (PV) Generation

CONSULTANT REPORT

Prepared For:
California Energy Commission
Renewable Energy Program

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April 7, 2004
500-04-065

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Memorandum

Presented to

California Energy Commission
Renewable Energy Program

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Introduction

The purpose of this memorandum is to discuss the relative merits of distributed versus central photovoltaic (PV) power generation. PV technology converts sunlight directly into electricity and can be sited either at the end-use application as a distributed source, or as a centralized source to support substation/feeder or peak power loads.

Distributed PV

Distributed PV is typically installed on rooftops of residential and commercial buildings, Figure 1. Residential systems are usually between 1 to 4 kW in size and installed on pitched roof buildings, except for 2-4 family unit buildings, which may be flat roof installations. System components include: PV module, inverter, mounting structure, and wiring. Commercial building systems are also typically building integrated and range in size from 2 to over 1000 kW. Commercial building installations can replace curtain wall systems or placed in skylights and awnings, but the more typical installation is on flat roof buildings. System components are similar to residential, but the industry (notably players such as PowerLight and RWE Schott Solar) has developed roof-mounting systems that allow for installations on flat roof buildings without the need for roof penetrations. The majority of PV installations in California today is distributed PV. As of the end of 2003 there was a total of 59.8 MW (PTCac) of grid-connected PV installed in the State, 26.8 MW of which was installed in 2003[1]. Within distributed PV, the share of commercial building installations is increasing.

Figure 1. Examples of Residential and Commercial Building PV Installations

Residential 1- 4kW

Source: PowerLight

Commercial: Moscone Center, 675 kW

[1]Todd Lieberg, California Energy Commission, *Grid-Connected PV Capacity in California: 1981 to Present*, February 2004.

Examples of some commercial/institutional building installations in California include:

- Santa Rita Jail, Alameda County, 1.18 MW (PV Surface Area: 130,680ft^2);
- Ridgehaven Building, San Diego City, 66 kW (PV Surface Area: 6,500 ft^2); and
- Neutrogena Corporation, Los Angeles, 546 kW (PV Surface Area: 62,000 ft^2).

Central PV

Central PV applications are greater than 100 kW in size, with the majority being greater than 1 MW. Some of the largest central installations are:

- 3.9 MW in Rancho Seco, CA for Sacramento Municipal Utility District (planned expansion to 9 MW), Figure 2.;
- 3.8 MW in Springerville, AZ for Tucson Electric Power;
- 5 MW in Leipzig, Germany (due to come on line in July 2004);
- 4 MW in Hemau, Germany;
- 3.3 MW in Serre, Italy; and
- 5 MW project in Prescott, AZ (2.2 MW with combination of single axis and concentrators are currently on-line).

Figure 2. Example of Central PV Installation
Rancho Seco, CA 3.9 MW
Source: NREL

System components include: PV module, inverter, mounting structure, wiring, and sometimes single axis tracking to allow the PV modules to track the sunlight across North to South or from East to West to gain additional kWh throughout the course of the day. Output from a single axis tracking system can be higher by 17 – 25% compared to systems without tracking, without adding a proportional amount to the overall PV system installed price[2]. Central systems are typically ground mounted installations, and therefore may have added costs associated with land preparation, land costs, foundations, permitting, and mounting structure. In general, a single axis tracking system can add 17% to the installed system price of a large commercial building installation[3].

[2] Interview with Herb Hayden, Solar Program Coordinator, Arizona Public Service, February 2004.
[3] Interview with Ray Kosanke, Global Solar Energy, February 2004.

Siting Issues and Land Requirements

Distributed PV

Distributed PV is typically customer sited on building rooftops and therefore, no land costs are associated with the installations. Distributed PV is in fact, one of the few renewable energy resources that can be easily customer sited on pitched or flat roof buildings. Some distributed PV installations are an actual part of the building construction, and can replace the material cost associated with a new or replacement roof, curtainwall or atrium ceilings. Shading of PV panels reduces system output and can thus be an issue. In residential building installations, shading can occur from trees, other buildings, vents and chimneys. Residential areas also run the risk of shading from trees not being an issue when the PV system was installed, but becoming an issue a few years later when a tree may grow taller and shade the panels. To address this problem, locations in California ensure solar access for installed PV systems through solar easements.

Shading of flat roof commercial building PV installations is caused by heating, ventilation, and air conditioning (HVAC) equipment, vent stacks, steps in roofs, other buildings, skylights, signs, billboards and antennas. Large obstructions can shade areas up to seven times that of the roof-mounted object's footprint. For example, assuming that a typical obstruction is a cube with six foot sides, there will be significant shading at places on the roof that "see" the obstruction at an elevation angle greater than 30 degrees in directions from southwest clockwise to the north and back to the southeast, and at 60 degrees from southeast to southwest.

Flat plate PV technology makes use of direct and diffuse sunlight that can be captured in any location throughout the state – this is unlike other technologies such as wind or geothermal which need to be near the high wind and good geothermal resource locations. Installing PV at the end-use also helps reduce transmission and distribution (T&D) losses. It is estimated that transmission losses of about 5 -10% can be saved by placing power at the end-use load center.[4] Further, strategically locating PV systems (e.g. in areas of high T&D congestion or step-down substations at the T&D interface) can also help to defer transmission upgrades.

Central PV

Central PV requires large land areas without shading, ideally in a location that is close to transmission lines. Tree or other obstruction shading is usually not a concern for central station applications as they are typically sited in remote scrub or desert areas. These very remote areas can sometimes provide lower priced land costs, but lack of access to nearby transmission lines can be an issue. Extending transmission lines to a site can be very costly.

[4] Interview with Herb Hayden, Solar Program Manager, Arizona Public Service, February 2004.

Land lease or land costs must be factored in to the economic analysis of central systems. These systems are installed at latitude tilt + or - 15% so more space is required for the same power output of a flat roof, horizontal installation that would not have the same amount of shading concerns between the rows of modules. A horizontal solar array can accommodate 100% more solar panels on an unshaded area so that the flat array will produce 167% of an optimally tilted array, without tracking, on a kWh/kW basis.[5]

Aesthetics

Distributed PV

Distributed PV on flat roof commercial buildings are rarely visible from street level if they are mounted flat or with a minimal tilt (5-10 degrees). Aesthetics are therefore not often an issue for commercial building installations. Residential installations are more visible as they are typically installed on pitched roofs, and can be an issue. However, product development efforts by leading PV manufacturers are beginning to address this problem – new modules are being launched in black colors with minimal white spaces and mounted on black systems, which gives the PV the look of a skylight that blends with the building. Some manufacturers are also making building integrated systems, which replace the roof rather than 'standing above the roof" and therefore appear more seamless with building lines. In addition, one company is making triangular modules so as to more aesthetically cover roof spaces.

Central PV

Central PV, by comparison, are very visible installations. They are ground mounted and tend to be in open spaces. The advantage of these systems, however, is that they are also often in somewhat remote locations with open space, so many people do not regularly see the installations. Aesthetics, therefore, are not often a consideration, except where a pristine or sensitive view-shed may be affected.

Visibility/PR Value

Distributed PV

Distributed PV on buildings can provide positive feelings of ownership and environmental responsibility for the building owner as well as public relations benefits to commercial building owners. A PV installation on a building can publicly promote the owner's commitment to environment stewardship, and therefore commercial building owners may want the PV system to be as visible as possible. Examples of companies that have installed PV for visibility and PR value include:

- Neutrogena headquarters in Los Angeles, CA (546 kW on three buildings);

[5] Navigant Consulting Inc. based on discussions with Ed Kern, Irradiance.

- Toyota Motor Sales headquarters in Torrance, CA (536 kW);
- Fetzer Vineyards administration building in Hopland, CA (41 kW);
- Yosemite National Park, El Portal, CA administration building (47 kW);
- U.S. Postal Service, Marina Mall Processing Center in Los Angeles, CA (127 kW); and
- Haywood Lumber, Santa Maria, CA (118kW).

System installations on commercial buildings also provide employees with direct "feel good" factor about helping the environment. For installations that are supported by the local utility, ratepayers prefer to see where their dollars are being spent to support renewable energy technologies. A visible PV installation provides tangible evidence of a utility's renewable energy commitment as well as caters to their customers' preference for programs that have local benefits.

Central PV

Central PV can provide visibility and public relations value as well, depending on the location of the installation. Utility customers, however, do not get a direct feeling of personal responsibility from these more centralized PV installations.

Permitting/Interconnection

Distributed PV

Distributed PV typically requires a building permit, as does any structural or architectural change for a building. However, if the structure is being newly constructed or remodeled, installation of PV typically does not require an additional permit if it is included in the permit application.

Since PV installations are still relatively new, however, there are some building code and enforcement officials that may require additional steps/review atypical of a normal permitting process. Currently there are 20 communities in California that have enacted laws that make it harder to install PV systems on homes.[6] In Los Gatos, CA for example, Akeena Solar was notified by local officials last year to erect a fence to hide modules after a city inspector reported being able to see them from the street, which is a violation of the their municipal code. Many state level building code officials still need to be educated about PV and its safety, reliability, and environmental benefits as this can result in installation delays or added costs. Sharp Solar noted that there are locations in California such as Santa Anna where they have actually stopped selling PV systems as the building inspectors where making it too difficult to install PV systems.[7]

[6] Jim Carlton, the Wall Street Journal, *People Favor Solar Power – but Not in Their Neighborhood*, February 25, 2004

[7] Interview with Art Rudin, Director of Engineering, Sharp Solar, March 2004.

Interconnection approval is required by the utility. Utility interconnection approval can be a simple and inexpensive application process, especially for residential systems. The process in California is suppose to facilitate net metering interconnection for systems under 1 MW under Rule 21, but some utility areas such a PG&E have a broad service area and field personnel are more fragmented and potentially less informed about PV technology and interconnection. Applications that fail utility screens described in the Rule 21 Guidebook may be required to pay for a detailed interconnection study, which in turn may define work to be paid for by the applicant. Interconnection requirements are moving toward standardization and regulatory efforts over the past several years are working to remove hurdles for grid interconnection.

Central PV

Central station PV, on the other hand, would go through a permitting process similar to a new powerplant or other use of land, but there are far less environmental issues relative to a conventional plant. SMUD, for example, did not incur additional environmental costs other than normal construction limitations in the development of central PV stations at Rancho Seco or at Hedge Substation.[8] Because these projects were constructed on sites where utility facilities already existed, no permits were required and no Environmental Impact Report (EIR) was conducted. Some reports are required for the project approval process, which may result in additional costs and project installation time.

APS estimates that the permitting and studies cost is less than 1% of the total project cost and the permitting time is about 4 to 6 weeks. Finding an acceptable site (relative to acceptable zoning) is more critical, as non-industrial zoning can require presentations at special use permit meetings.[9]

Central station facilities must also apply for interconnection to the utility. Given their size, they are more likely to require a costly interconnection study to determine their impact on the utility system. Central stations may incur system losses that are minimized by distributed generation. Sharp estimates that interconnection costs for a 5 MW PV system would be about $5,000.

Roof Warrantees/Penetration

Distributed PV

Distributed PV on building rooftops may need to take into account issues associated with roof warrantees. Building owners may be concerned with the impact on roof warrantees

[8] Interview with Jim Skeen, Sacramento Municipal Utility District, March 29, 2004.

[9] Interview with Herb Hayden, Solar Program Manager, Arizona Public Service, April 5, 2004.

because of added weight to the roof of the installation, damage associated with increased "walking traffic" from contractors walking on roof to install the PV system or from any roof penetrations required for the installation of the PV system. For residential customers, this is often not an issue, and the CEC's Emerging Renewable Program requires five-year warrantees.[10] Most commercial systems installed in California as well, do not require roof penetrations and come with five-year warrantees, so roof penetrations is not as much of an issue as it was several years ago when roof penetrations where required for many flat roof, commercial building PV installations.

Central PV

Central PV does not have issues associated with roof warrantee or penetrations.

Solar Industry Impacts

Distributed PV

Distributed PV has high transaction costs, especially for residential systems, given existing business models for marketing and sales. The amount of marketing time it takes to sell a residential system of 3 kW is about the same amount of time that it takes to sell a 250 kW commercial system.[11] These additional indirect costs can add substantially to the total installed cost of a smaller, distributed PV system. However, smaller, distributed PV requires many more unique installations than larger distributed or central station systems, each of which results in demand and hence jobs for installers and electricians.

Central PV

Central PV by comparison, are large multi-MW installations, so transaction costs will be less on $/kW installed basis. Sales of central PV systems help to stimulate manufacturing and construction jobs, but there will be less retail jobs for the same MW installed compared to distributed PV, due to the nature of the sale and installation.

Performance Issues

Operation and Maintenance Issues

Distributed PV

Distributed PV has minimal operation and maintenance (O&M) costs. PV systems have proven reliability and there may be occasional maintenance requirements such as cleaning PV panels, but in general the costs are minimal. Inverter replacement may be needed around year 10, but overall it is estimated that O&M costs are around $14/kW-year for

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[10] **Emerging Renewables Program Guidebook - Second Edition**, California Energy Commission Publication # 500-03-001F, December 17, 2003, http://www.energy.ca.gov/renewables/guidebooks/500-03-001F.PDF

[11] Solar Energy Business Association of New England, 2004.

residential and $12/kW-year for commercial building installations (or about 0.5 – 1.0¢/kWh).[12]

Central PV

Central PV can have single axis tracking to optimize PV system output. As stated earlier, output from a single axis tracking system can be 17 – 25% higher than systems without tracking[13]. These tracking systems have moving parts such as drive actuators and controls that may require more routine maintenance, but some of these additional costs can be offset by the economies of scale associated with central systems. In addition, central PV systems are often in open spaces without trees, so dust accumulation may need to be addressed through occasional washing of the modules. However, central systems are likely to be better maintained through this regular cleaning of the PV modules which could ensure slightly higher output compared to smaller distributed systems that do not receive regular cleaning. Dust issues can be better or worse than distributed PV locations, depending on the site location selected. O&M costs for central systems can range from $28 – 55/kW- year (or about 1.5 – 3.0¢/kWh).

Cell Performance

Distributed PV

Distributed PV is located on building rooftops and is often not directly mounted on to the roof. There is often a small gap between the PV installation and the rooftop that allows for air circulation to reduce heat build-up. This is important, as higher temperatures of PV crystalline silicon solar cells reduces performance. The output of the cell will reduce about -0.5% for every °C above Nominal Operating Cell Temperatures (NOCT) under PV-USA Test Conditions (PTC) (20 degrees C ambient).

Central PV

Central PV are not on rooftops, but may be in more remote, desert like conditions with higher outdoor temperatures. Crystalline silicon solar cells captured over 90% of the total worldwide installation in 2003. If crystalline solar cells are used for centralized applications in warmer locations, cells will be operating at higher temperatures and therefore may have reduced performance.

Other Electric System Issues

Distributed PV

In addition, distributed systems can provide local voltage support services, and can delay or replace needed distribution system upgrades. During blackouts or electrical system problems, distributed PV systems could present a safety issue to utility personnel if not

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[12] Interview with Ray Kosanke, Global Solar Energy, February 2004.

[13] Interview with Herb Hayden, Solar Program Coordinator, Arizona Public Service, February 2004.

properly installed. On the other hand, these systems can provide on-site electric service during electric system interruptions if installed with batteries and appropriate switchgear, and can assist in returning to a fully-functioning electric system. Distributed PV can reduce peak utility loads that often coincide with peak AC loads and PV output. Some installations on flat roof commercial buildings also provide added insulation value and therefore some additional energy savings, but the temperature of the cells can get hotter and result in reduced cell performance.[14]

Central PV

Central PV also reduces peak utility loads, and single axis tracking will provide more kWh/kW to help reduce utility peaks and to extend the peak PV system output to earlier and later in the afternoon.

Other Energy and Material Impacts

Distributed PV in both residential and commercial applications can reduce cooling loads and reduce need for roofing materials, either because they replace part of the roof or they extend roof life.

Typically, a distributed system will require a less extensive mounting structure, reducing material use and costs.

Economics

The levelized cost of energy (LCOE) was assessed for three PV systems installations: a 3 kWpdc, peak direct current (distributed), a 250 kWpdc commercial (distributed) and 5 MWpdc central single axis tracking (central). The key assumptions are provided in Table 1 in the Appendix.

The economics was evaluated within the following framework:

- The analysis was conducted from the perspective of the PV system owner rather than the perspective of the utility or the grid system. Thus, the effective LCOE for distributed PV systems is compared to the retail power rates, rather than evaluating the impact of distributed PV systems on the T&D investment, T&D system losses, reduction in peak power and other factors that could impact the overall utility system cost.
- The economic impact on other ratepayers retail revenue losses from the customer installing the PV system is also not considered.

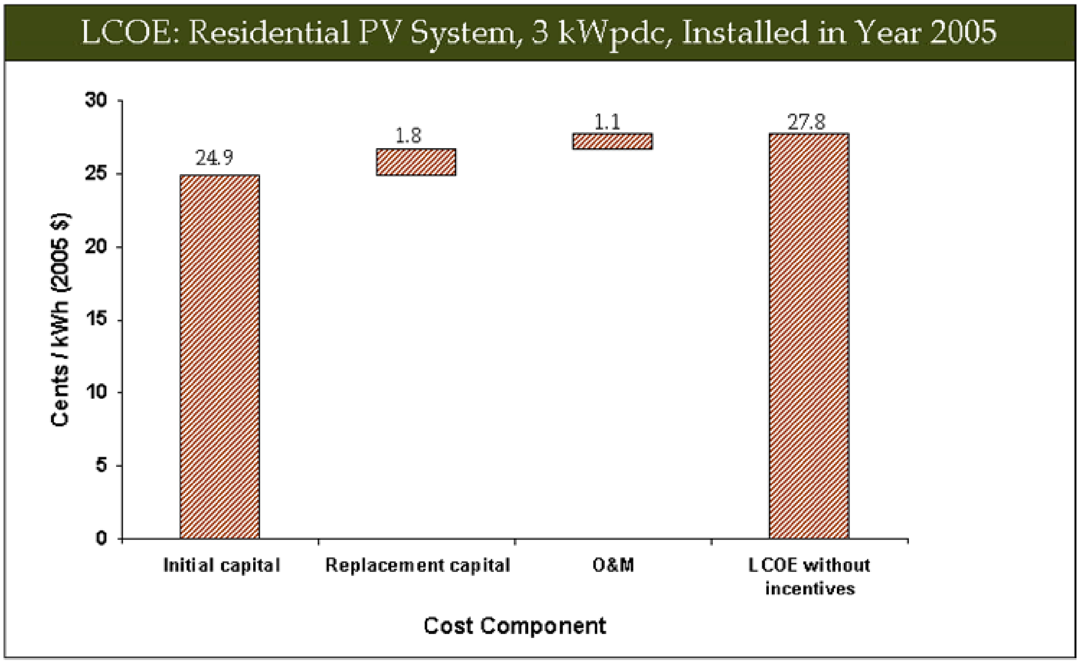
[14] Interview with Herb Hayden, Solar Program Coordinator, Arizona Public Service, April 7, 2004.

* The economic impact of state buy-downs on ratepayers who do not own distributed PV systems is not considered.

Distributed Residential Systems

The LCOE estimation and its components for the residential system are presented in Figure 3a and 3b below, reflecting different discount rates.

Figure 3a: Residential System Economics: 4% Discount Rate



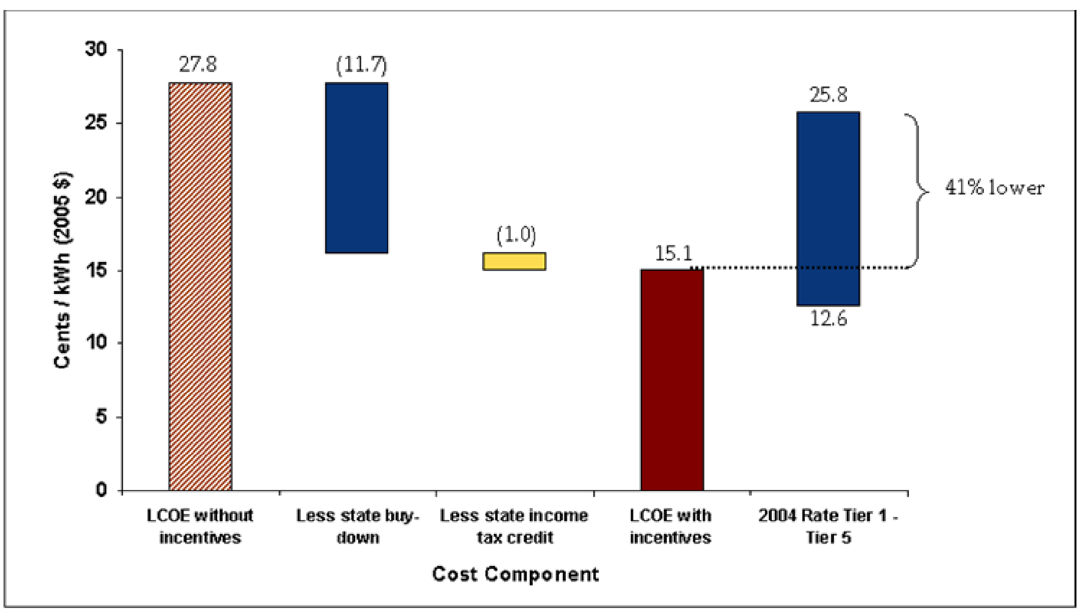
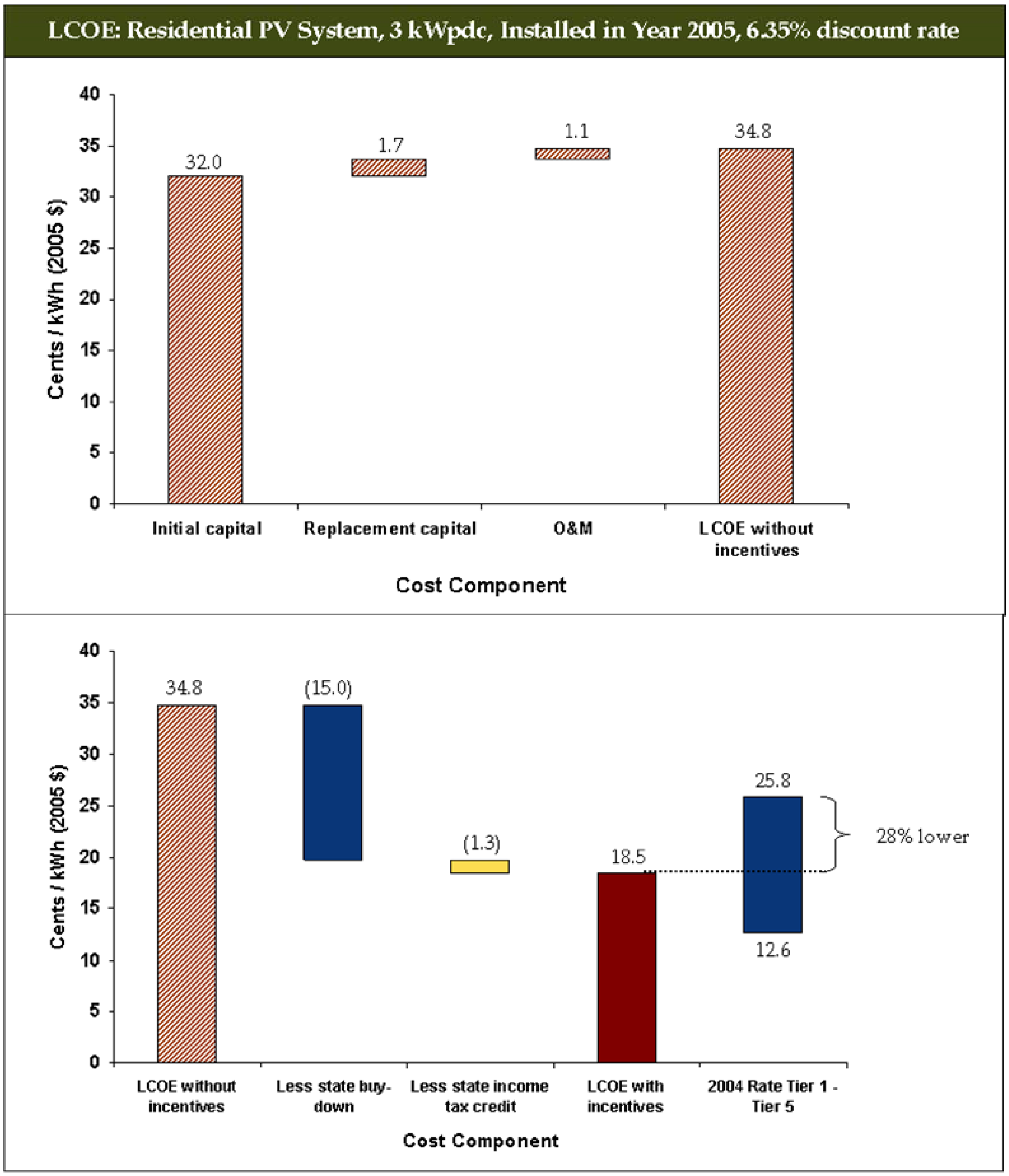


Figure 3b: Residential System Economics: 6.35% Discount Rate



Note: Source of 2004 Rate Tier 1 – Tier 5: Xenergy

The key findings are:

- The cost to the consumer is equivalent to a LCOE of 27.8 – 34.8 ¢/kWh without any incentives.
- Total incentives available to residential customers are 12.7 – 16. 3 ¢/kWh, which is contributed as follows:

Incentive Contributor	Cost (¢/kWh)
By state IOU ratepayers through state buy-down	11.7 – 15.0
By state taxpayers through state income tax credit	1.0 – 1.3
Total	12.7 – 16.3

- With the incentives, the cost to the customer is 15.1 – 18.5 ¢/kWh.
- The average cost of grid electricity to residential customers ranges between 12.6 - 25.8 ¢/kWh, depending on the tier rate structure applicable to the customer.
- For residential customers on the high tier rate structures, the value of distributed PV systems is significant, with a possible 7.3 - 10.7¢/kWh or a 28-40% reduction in average cost per kWh.

Distributed Commercial System

LCOE estimation and its components for the commercial system are presented in Figure 4.

Figure 4: Commercial System Economics

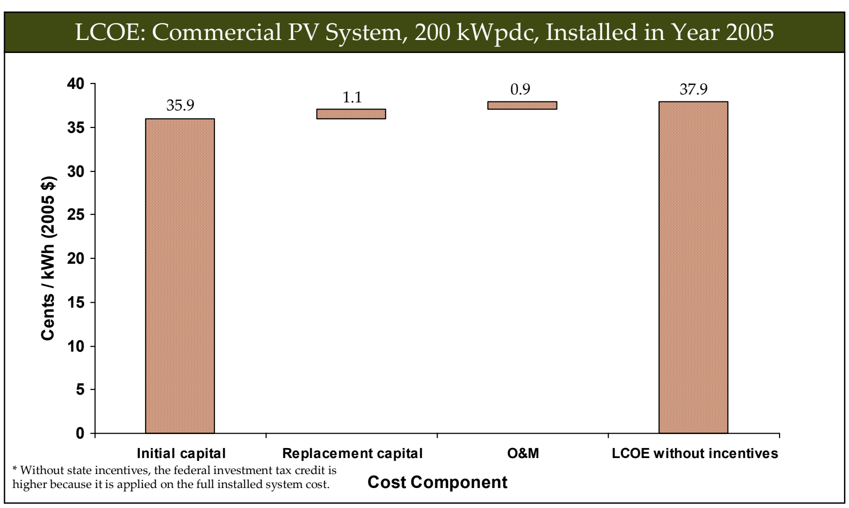
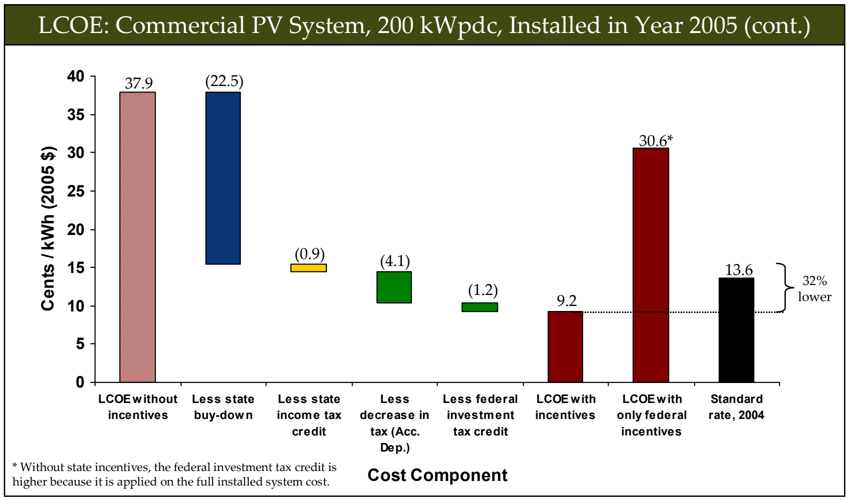


Figure 4: Commercial System Economics (continued)



Note: Standard Rate, 2004, for a customer with peak demand <499 kW. The demand change affects the average rate per kWh.

The key findings are:

- The cost to the consumer is equivalent to a LCOE of 37.9 ¢/kWh without any incentives.
- The per kWh basis for commercial systems calculated here is higher than for a residential system despite a lower installed system cost because of a higher discount rate relative to 3a above and the levelizing of cost over a loan period of 15 years.
- Total incentives available to commercial customers is 28.7 ¢/kWh, which is contributed as follows:

Incentive Contributor	Cost (¢/kWh)
By state rate payers through state buy-down	22.5
By tax payers:	
State taxpayers through state income tax credit	0.9
Federal taxpayers through federal incentives	5.3
Total	28.7

- With all the incentives, the cost to the customer is 9.2 ¢/kWh.
- The average cost of grid electricity to commercial customers is 13.6 ¢/kWh.
- Distributed PV thus represents a significant value to commercial customers, at a possible 4.4 ¢/kWh (13.6 – 9.2) or a 32% reduction in average cost per kWh.

- Without the state -incentives, and considering only the federal incentives, distributed PV commercial systems do not generate value for the customer, as the LCOE would be around 30.6 ¢/kWh, or more than two times the cost of grid power.

Central System

The LCOE for central systems was assessed for two locations – the first for the same location as assumed for residential and commercial systems, and the second at a location similar to Barstow, CA, which has a higher insolation. The installation of a central PV facility can reasonably be expected to avoid the cost of peaking capacity in California. As such, the LCOE of a central PV system is compared to the cost of a peak plant. The capital costs for peaking capacity translate into a capacity cost on the order of 10 ¢/kWh assuming use exclusively during the super-peak period. When energy costs are added, the all-in cost for super-peaking capacity can be expected to range from 13 to 17 ¢/kWh. For peaking capacity, this is expected to range from 7-10 ¢/kWh due to higher capacity factor of 19%, similar to that assumed for the PV central plant.

The LCOE and components for a central PV system in two locations is presented in Figure 5.

Figure 5a: Central System Economics, Lower Insolation

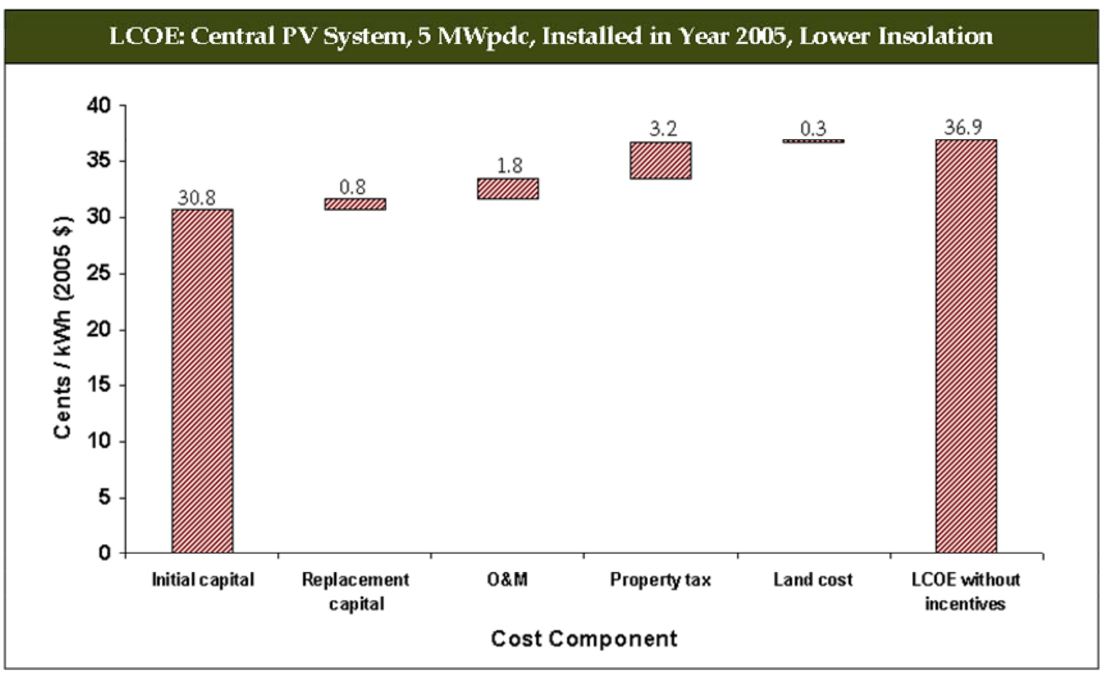


Figure 5a: Central System Economics, Lower Insolation (continued)

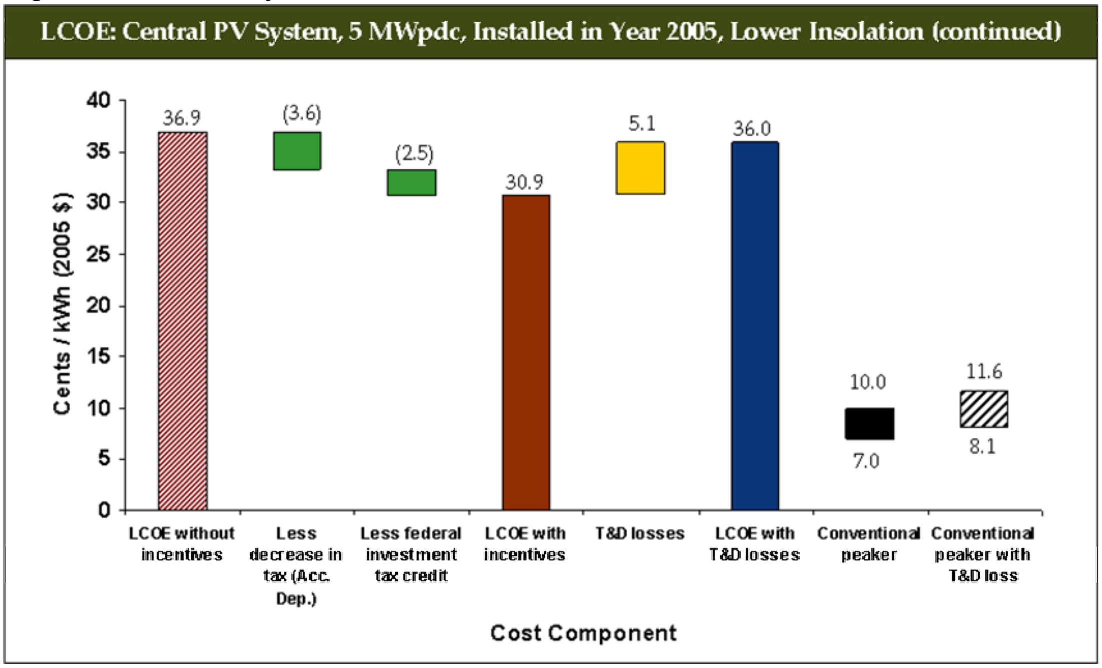


Figure 5b: Central System Economics, Higher Insolation

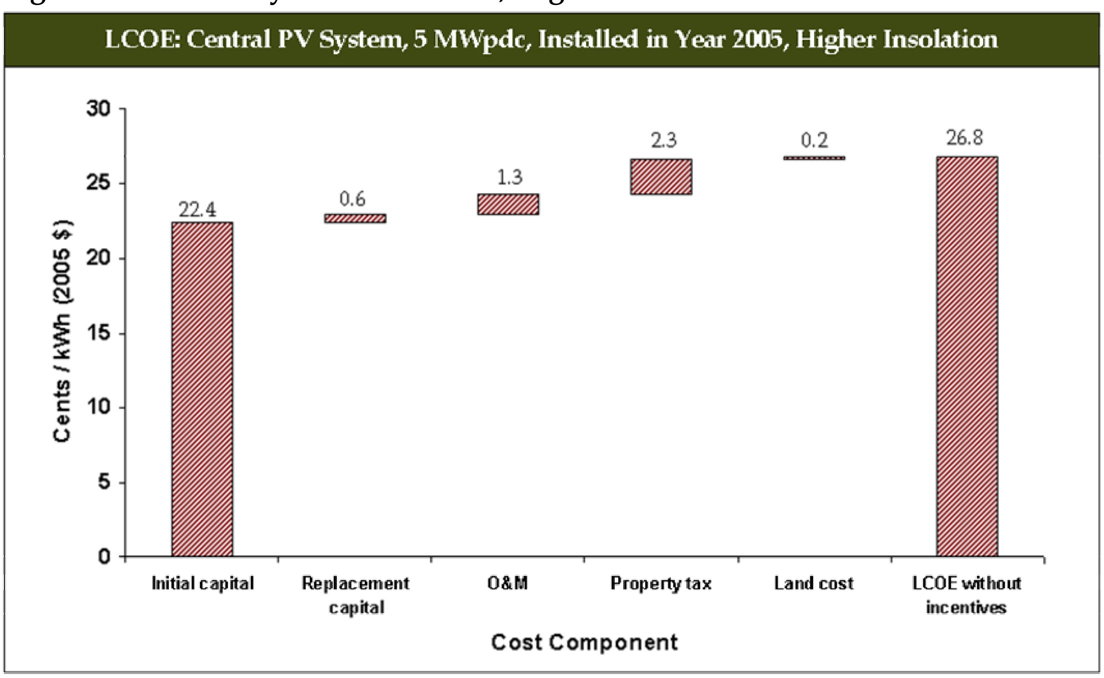
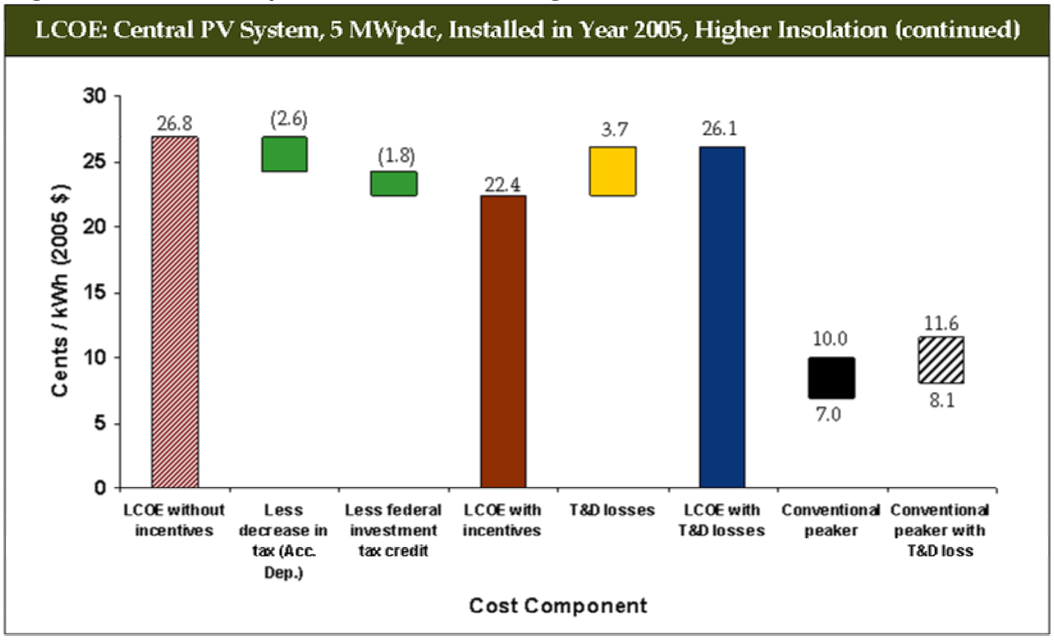


Figure 5b: Central System Economics, Higher Insolation (continued)



The key findings are:

- The cost of PV power from a central plant is 26.8 - 36.9 ¢/kWh without any incentives, depending on the location.
- In comparison, the LCOE of a fossil fuel super-peak plant is 7-10 ¢/kWh.
- It is assumed that only federal incentives are available to a central PV.
- In evaluating the cost of centrally generated electricity (both PV and fossil fuel super peak plan) at the distribution level, the loss of power in the T&D system is considered. This loss results in a higher cost per kWh, and is essentially borne by the ratepayers. The cost of the T&D system is however not taken into account, i.e. only the energy cost is considered.
- The LCOE cost components are incurred as follows:

Contributor	Cost (¢/kWh)
By ratepayers for PV system cost	22.4 – 30.9
By ratepayers for T&D losses in system	3.7 – 5.1
By federal taxpayers for federal incentives	4.4 – 6.1

Summary

The LCOE for distributed and central PV systems is summarized below.

PV System	Cost to Stakeholder (¢/kWh)				Cost of PV Power to Consumer (¢/kWh)	Grid Power Cost (¢/kWh)
	Customer (PV system owner)	State Tax Payer (State tax incentives)	Federal Tax Payer (Federal tax incentives)	State Rate Payer (buy-downs, T&D losses, central PV system cost)		
Residential Distributed	15.1 – 18.5	1.0 – 1.3	-	11.7 – 15.0	15.1 – 18.1	12.6 – 25.8
Commercial Distributed	9.2	0.9	5.3	22.5	9.2	13.6
Central	-	-	4.4 – 6.1	PV system: 22.4 – 30.9 T&D loss: 3.7 – 5.1	26.1 – 36.0 (does not include T&D system cost)	15.1 – 19.8

It must be noted that the aggregated impact of distributed PV systems on the utility system (reduction in peak power, deferral of T&D investments) is not considered. Further, the economic impact on ratepayers who do not own distributed PV systems has not been considered in this analysis and nor has the aggregated impact of substantial penetration of central station systems on the utility system been considered. One central station system at a 5 MW size can probably be connected to the existing transmission system without substantial improvements being necessary. However, larger or more numerous central station systems totaling 1,000 MW or more could lead to significant transmission costs.

Appendix

Table 1. Assumptions for Economic Analysis in 2005

Assumption	Note	Distributed Residential	Distributed Commercial	Central Single Axis Tracking
PV System Related				
Size (kW)	1	3	200	5,000
Installed Price ($/kWac)	2	8,000	6,000	7,000
AC rating as % of DC rating	3	80%	80%	80%
O&M Cost ($/kWpdc/yr)	4	14	12	30
Capacity Factor (%)	5	16%	14%	20% and 27%
PV System Life (years)	6	25	25	25
Land Cost	7	None	None	$6000/acre
T&D Losses	8	--	--	14%
Incentives and other payments related				
State buy-down ($/Wpdc)	9	None/ $3.00	None/ $3.00	None
State income tax credit	9	7.5%	7.5%	None
Federal Incentives	10	None	10% ITC Accelerated depreciation	10% ITC Accelerated depreciation
Property Tax Exemption	11	Yes	Yes	No
Renewable Energy Certificate	12	None	None	None
Tax rate and discount rates related				
State Income Tax (%)		-	6.5	6.5
Federal Income Tax (%)		-	34	34
Property Tax	13	-	-	1.5%
Discount Rate (%)	14	4 and 6.35%	6.35	6.35
Debt/Equity		-	3:1	3:1
Cost of Debt (%)		-	7.5	7.5
Cost of Equity (%)		-	12	12
Loan Terms (years)		Cash payment	15	15

1. Residential systems - based on average system size of installations. Commercial system - sizes vary significantly, from 10kWp – 800 kWp, though the trend is towards larger system sizes.
2. Installed system price in 2005. The system cost for the central plant takes into account the single axis tracking system. The upper end of the price range was modeled. APS has quoted that $5,500/Wpac can also be obtained. More details are provided in Table 2.
3. AC to DC rating factor takes into account system losses (dust, wiring, module mismatch), system equipment efficiencies (inverter) and impact of temperature on PV system output.

4. O&M costs are minimal for residential and commercial systems, but verification of system performance is also less frequent than centralized PV systems. Central plants typically have higher O&M because of the labor cost involved to clean PV panels on a regular basis (specially in areas prone to dust), check system connections, conduct maintenance of inverters, and to maintain the drive actuators/controls.
5. The capacity factor for the central plant is higher than a residential PV system by around 18 - 25% because of the North-South, single axis tracking. Note that capacity factors in locations such as Barstow, CA can be as high as 27%. Both a 20% and 27% capacity factor was modeled.
6. Most PV manufacturers offer a warrantee of 25 years for crystalline silicon modules.
7. Land cost includes cost of land as well as costs incurred for land preparation, which can vary significantly by location, depending on whether the land is level or rocky. Site selection should be such that the land cost is around 1% of the PV installed system cost. The land area required for a central PV system is assessed based on a density of 100 – 150 kWp/ acre of land – this takes into account requirements of the single axis tracking system as well as avoidance of shading, with PV panels accounting for 50% ground coverage (e.g. a module row with a width of 4 ft. would require 4 ft. of dead space between the rows).
8. Typical T&D losses average 10%. In comparing central PV to distributed PV, an additional 4% loss is associated with stepping up centrally generated power for transmission.
9. State incentives are assumed to be applicable only for distributed generation facilities. The state income tax credit is applied to the installed system cost net of state subsidy and federal investment tax credit. This incentive is currently applicable to systems installed by January 2006, and its extension is uncertain.
10. Federal incentives are applicable only to systems owned by commercial customers. In the case of the central plant, it is assumed that it is not owned by a utility and hence federal incentives will apply. The federal investment tax credit is applied to the system cost net of the state subsidy.
11. Property tax exemption is a state incentive and is assumed to be applicable only to distributed generation. This incentive is currently applicable to systems installed by January 2006, and its extension is uncertain.
12. No value is assumed for renewable energy certificates.
13. Property tax rate is applied to the net book value of the PV system, which is calculated using the straight-line depreciation method.
14. Discount rates vary across residential and commercial segments. We have assumed two discount rates for residential systems – one at 4% and the other at 6.35%, which is the same as assumed for commercial and central system. Given that the economics are sensitive to discount rate used, using the same discount rate of 6.35% allows for better comparison of the economics due to factors other than discount rate.

Table 2. Breakdown of Installed System Prices ($/kWac)

Assumption	Distributed Residential	Distributed Commercial	Central Single Axis Tracking
Size (kW)	3	200	5,000
Installed Price ($/kWac)	**8,000**	**6,000**	**5,500 - 7,000***
Modules	4,000	3,450	2,900 - 3,300
Inverters	1,000	450	350 - 430
Structure	150	250	400 - 500
Installation	800	150	440 - 600
Electrical	400	200	300 - 340
Design/Permits/Services*	100	200	100 - 200
Feeder Line Connection/Fencing	NA	NA	200
Controls/Comm./Data Acquisition	NA	80	80 - 100
Mark-up/Project Management	1,550	1,220	730 - 1,330

*Includes items such as Storm Water Pollution Prevention Permits; Cultural Resource Assessment; Geotech Survey; Site Civil report to the City for Flood Waters; and Design Wind Speed Report for Site.

Source: NCI estimates based on interviews with Herb Hayden, Solar Program Manager, Arizona Public Service, March 10, 2004 and Janice Lin, VP Business Development, PowerLight, March 2004.